



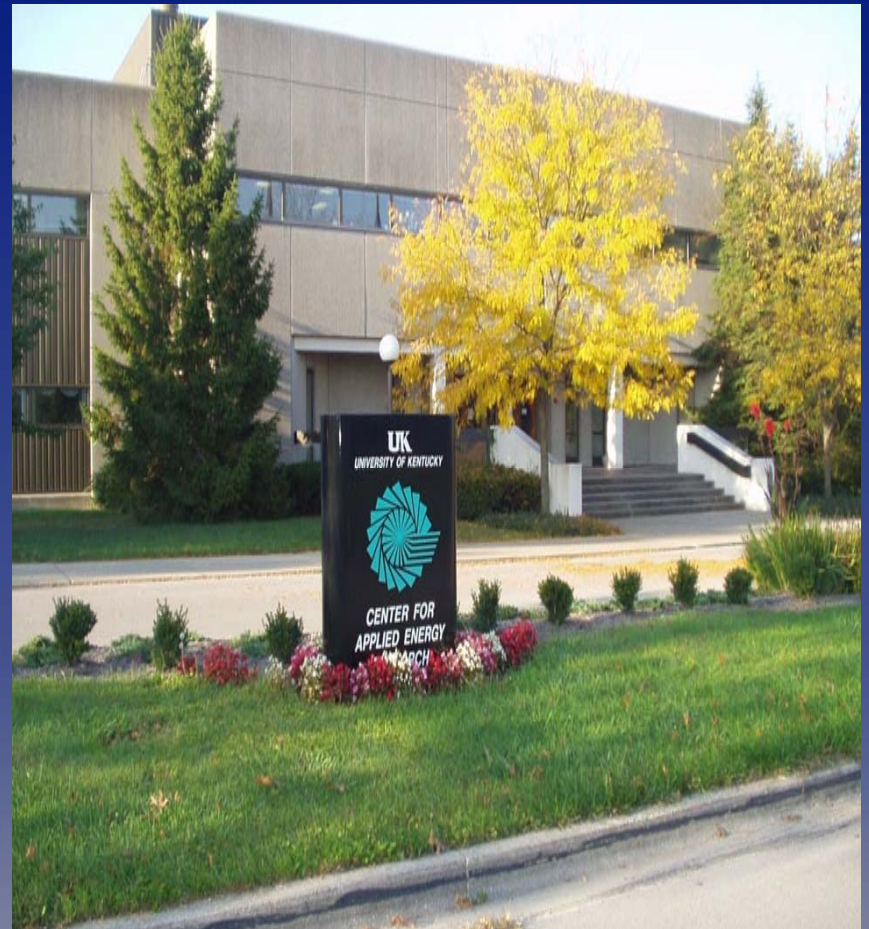
Coal-to-Liquids Technology

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Center for Applied Energy Research

Overview of CTL

- Introduction to CAER
- CTL Technology
- CAER FT Program
- CAER Emissions Program
- Future Research Directions





Introduction to CAER



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History of CAER

- Created by Act of the KY Legislature in 1974 – KRS 152A
- Laboratory opened in 1977
- Lab was intended to support growing synthetic fuels industry
 - coal and oil shale
- Laboratory and people transferred to the University of Kentucky in 1988





Current Resources

- Total Funding: ~\$9 Million
- 60% state funding
 - Includes overhead costs
- 40% grants & contracts (mostly federal)
- Research Staff
 - ~ 75 (1/2 PhD level, scientist and engineers)
 - Others – mainly research support
 - Additional 25 students and faculty



Research Areas

Mining

- Coal Prep/Cleaning
- Coal Slurry Ponds
- Mine Map Info

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Electric Power

- Generation
- Emissions Control
- Carbon Management
- Beneficial Re-use of By-products (ash, slag, FGD, etc.)

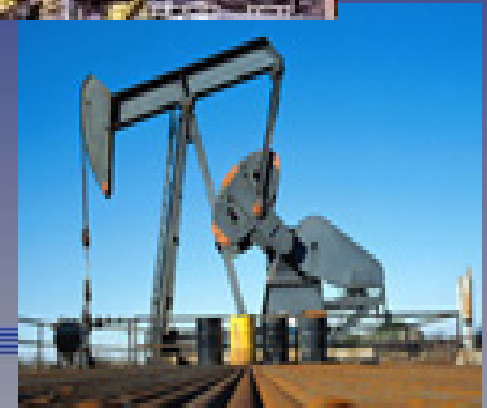
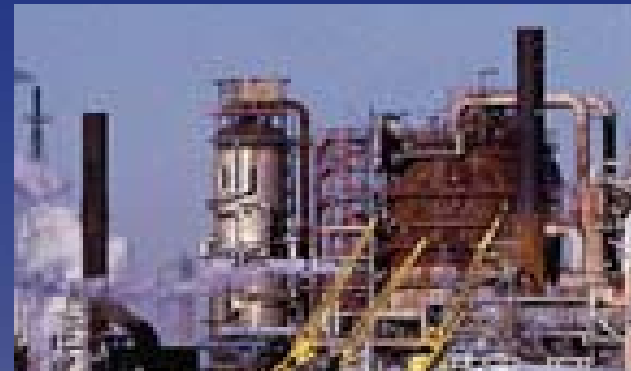




Research Areas

Fuels, Chemicals & Materials

- Coal-to-Liquids (CTL) Technologies
 - Catalyst Research and Testing Center
- Oil Shale Retorting
- Carbon Materials
- Environmental Catalysis
- Agricultural Bio-fuels
- Fuel Cells, Batteries and Devices





Energy Education

- CAER is a non-academic research center
- But has a strong role in experiential education
 - Provide support for 75 students/yr on average
- Student support
 - Mining engineering scholarships (\$40,000/yr)
 - 19 undergraduates working in CAER labs
 - 25 graduate students
 - 4 postdoctoral scholars
 - Biomedical, Biosystems and Agricultural, Chemical and Materials, Civil, Mechanical, Mining Engineering
 - Chemistry, Geology
 - Library Science

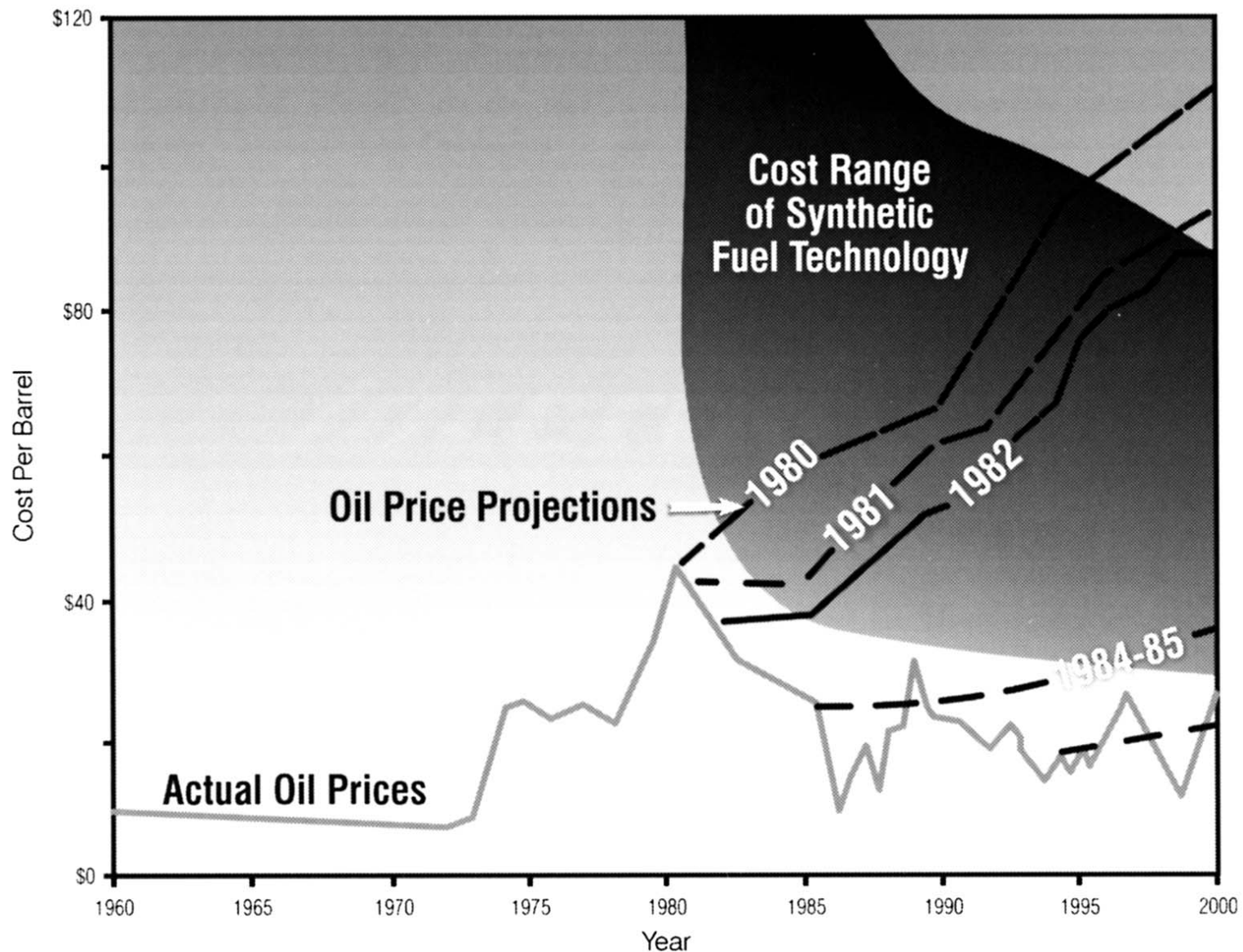


Coal-to-Liquids History at CAER

- Originally focused on direct liquefaction
 - H-Coal Plant
 - Still work on coal extraction for pitch and coke
- Indirect Liquefaction and Fischer-Tropsch
 - Program lead: Dr. Burt Davis
 - Funded by State, Federal and Industry
 - Research focus on:
 - Catalyst Development
 - Product Upgrading and Separations



Funding Cyclic with Oil Price

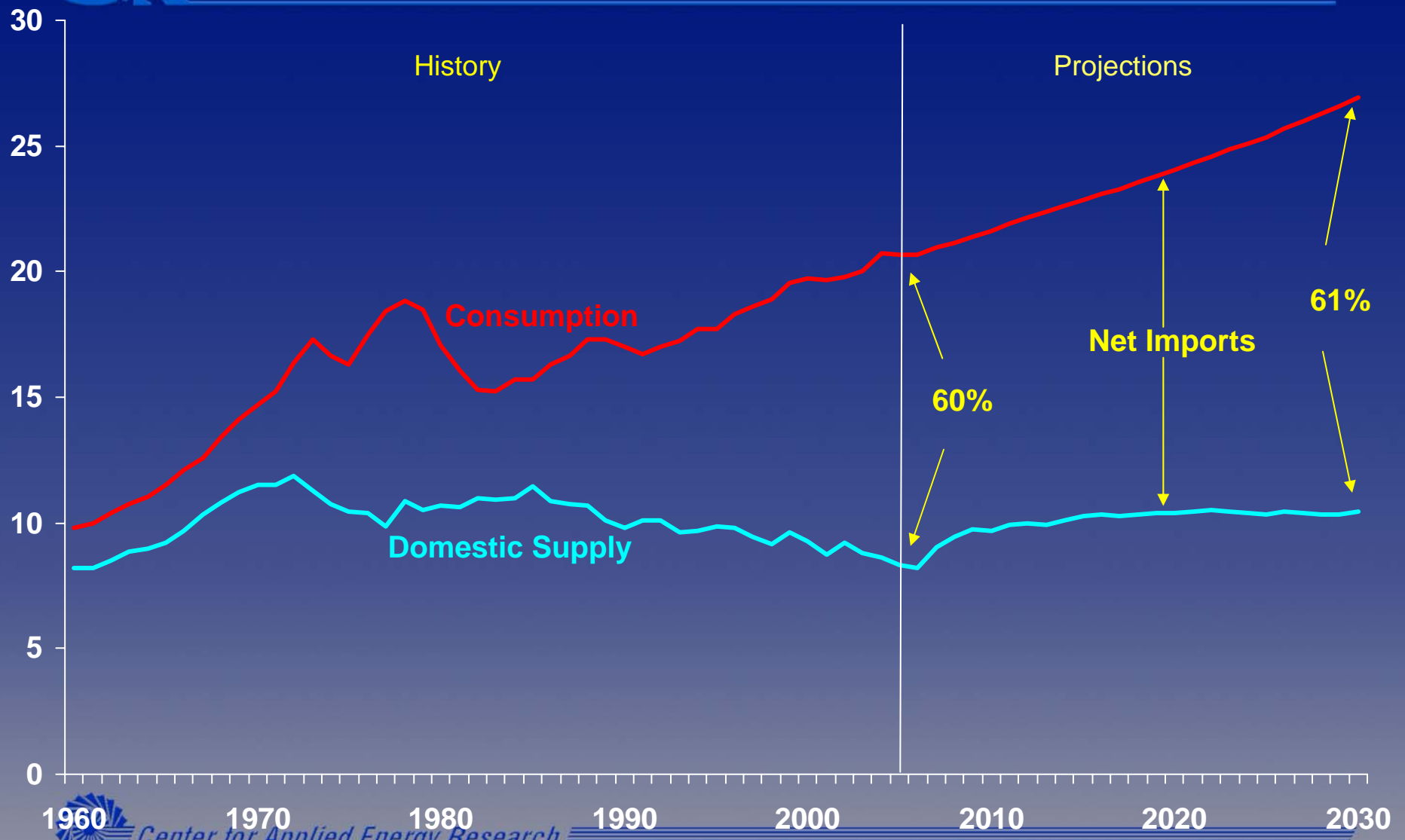


Coal – to – Liquids Technologies



U.S. Supply, Consumption & Imports

Liquid Fuels/Other Petroleum (MBD)





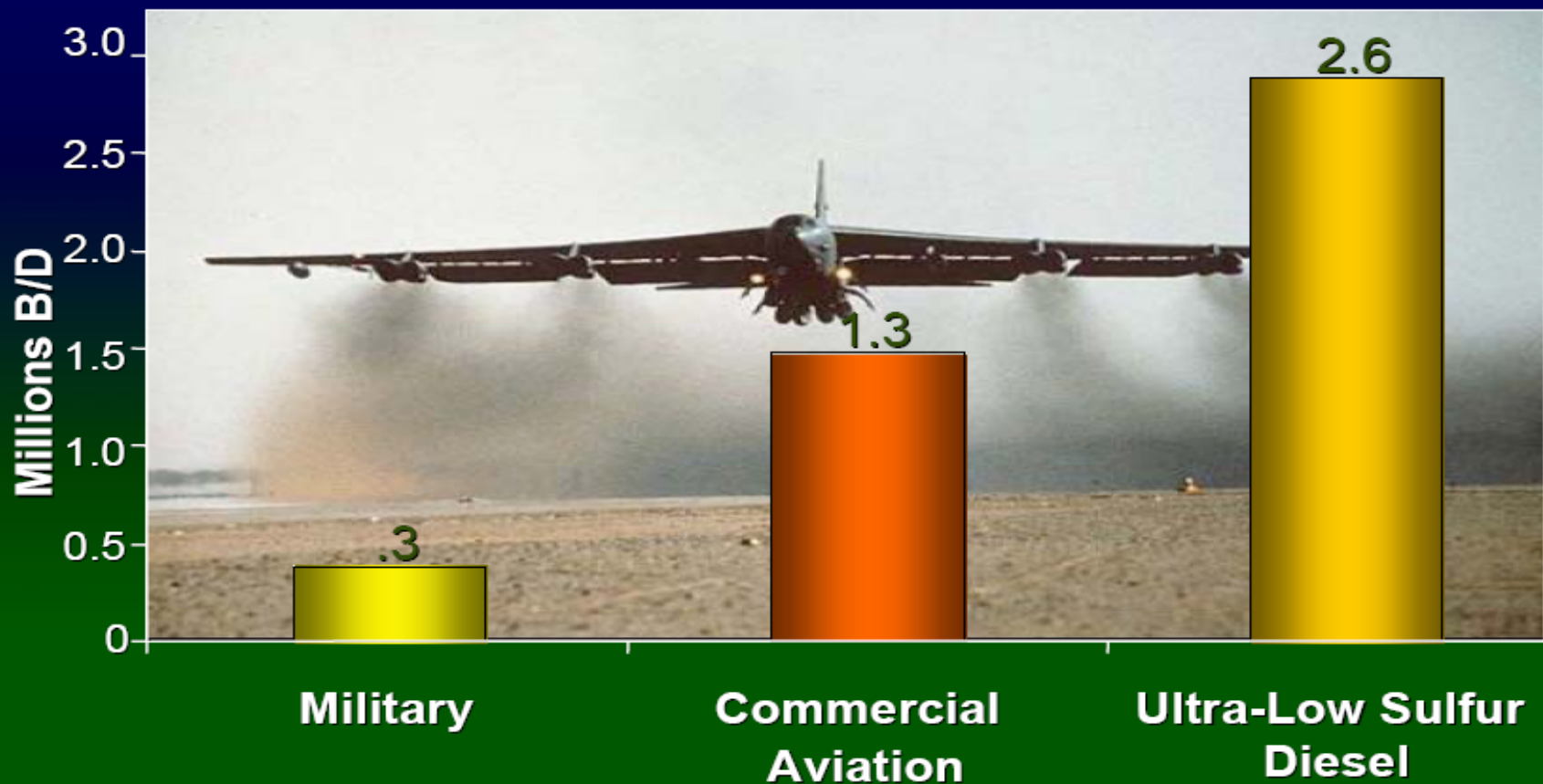
Alternative Liquid Fuels

- This year's reference case anticipates ... ***substantial development of unconventional production*** over the next 25 years. The prices in the AEO2007 reference case are high enough to trigger entry into the market of some alternative energy supplies that are expected to become economically viable in the range of \$25 to \$50 per barrel. ***They include oil sands, ultra-heavy oils, gas-to-liquids (GTL), and CTL.***
- AEO2007 includes, for the first time, a reorganized breakdown of fuel categories that reflects the increasing importance, both now and in the future, of conversion technologies that can produce liquid fuels from natural gas, coal, and biomass.

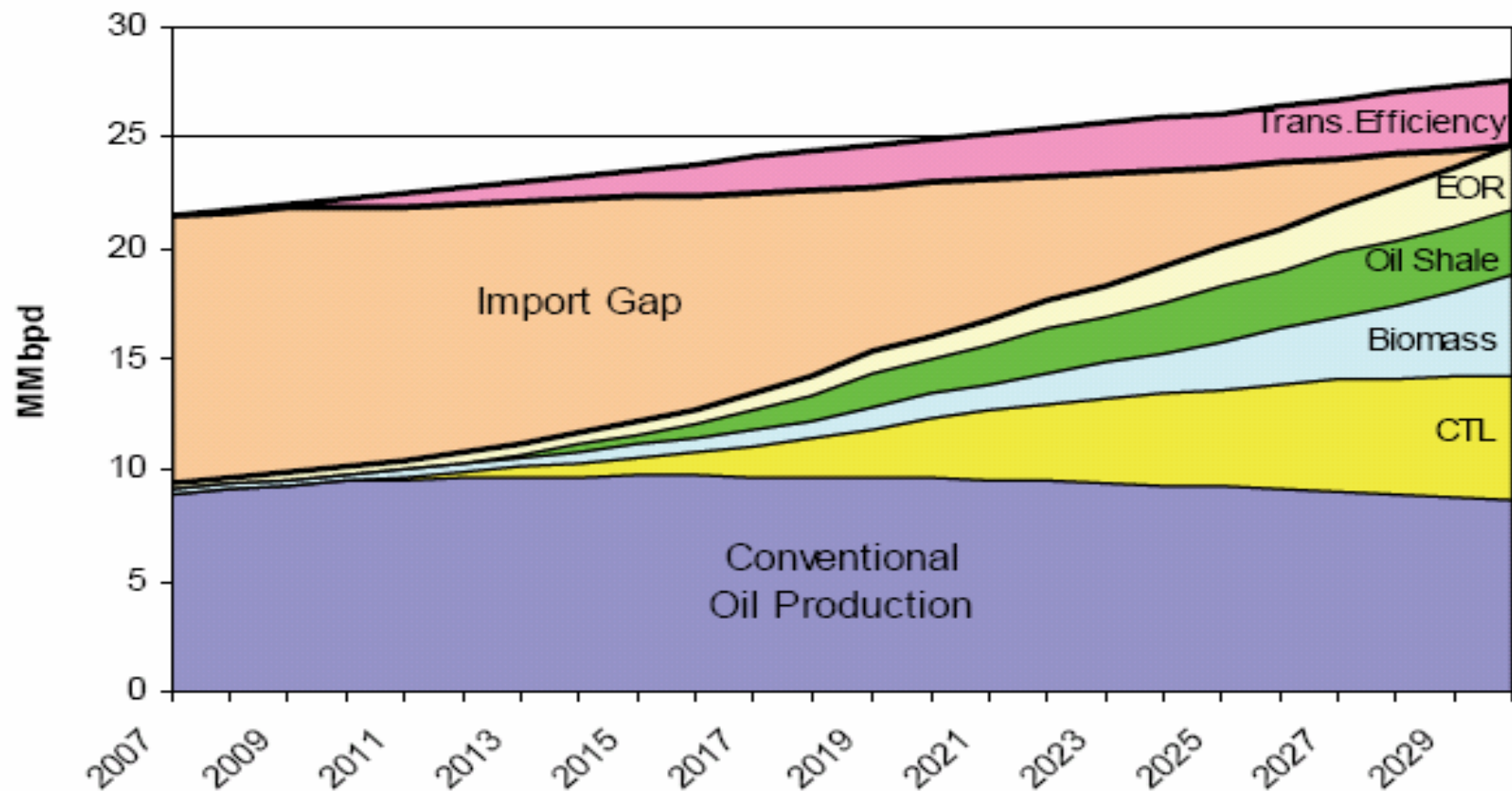


Demand for CTL

Is There a Market for FT Fuels?



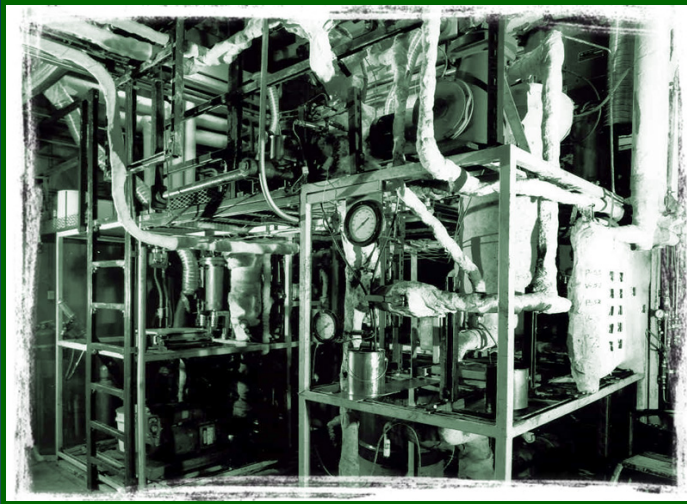
Closing the Gap will Require A Mix of Resources



Source: Southern States Energy Board and Management Information Services, Inc., 2006



UK Coal Liquefaction: Two Methods



Indirect: coal gasified with steam and oxygen and resultant CO and H₂ (syngas) is catalytically converted to liquid hydrocarbons at about 375psi (25 bar) and 400-630°F (200-340°C)

Direct: fine low-ash coal with catalyst; high pressure (3500psi/230 bar+) and temperature (750°F/400°C) reacts with hydrogen to produce liquid hydrocarbons and char-like residue

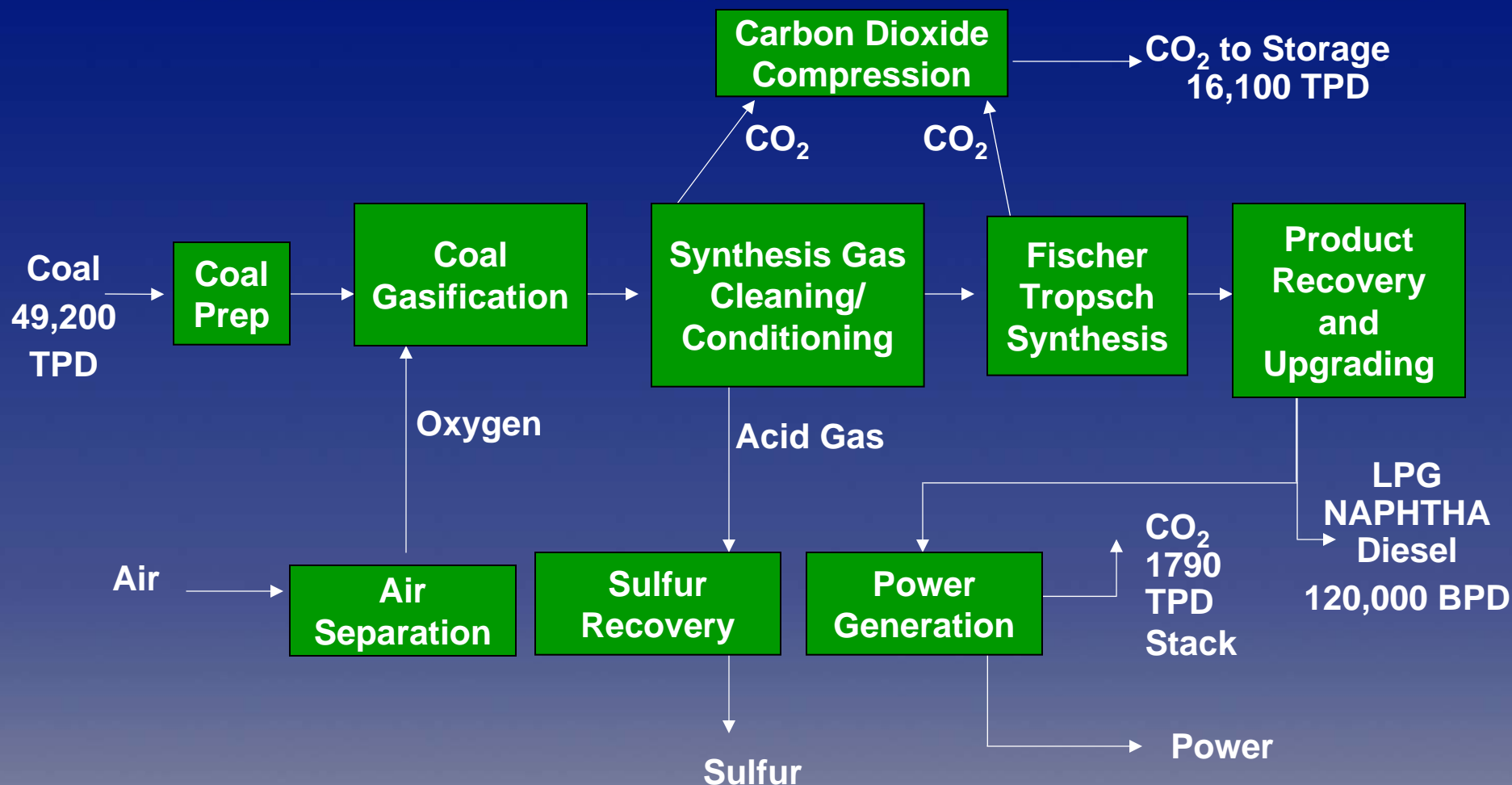


UK Indirect Liquefaction: Fischer-Tropsch (FT)

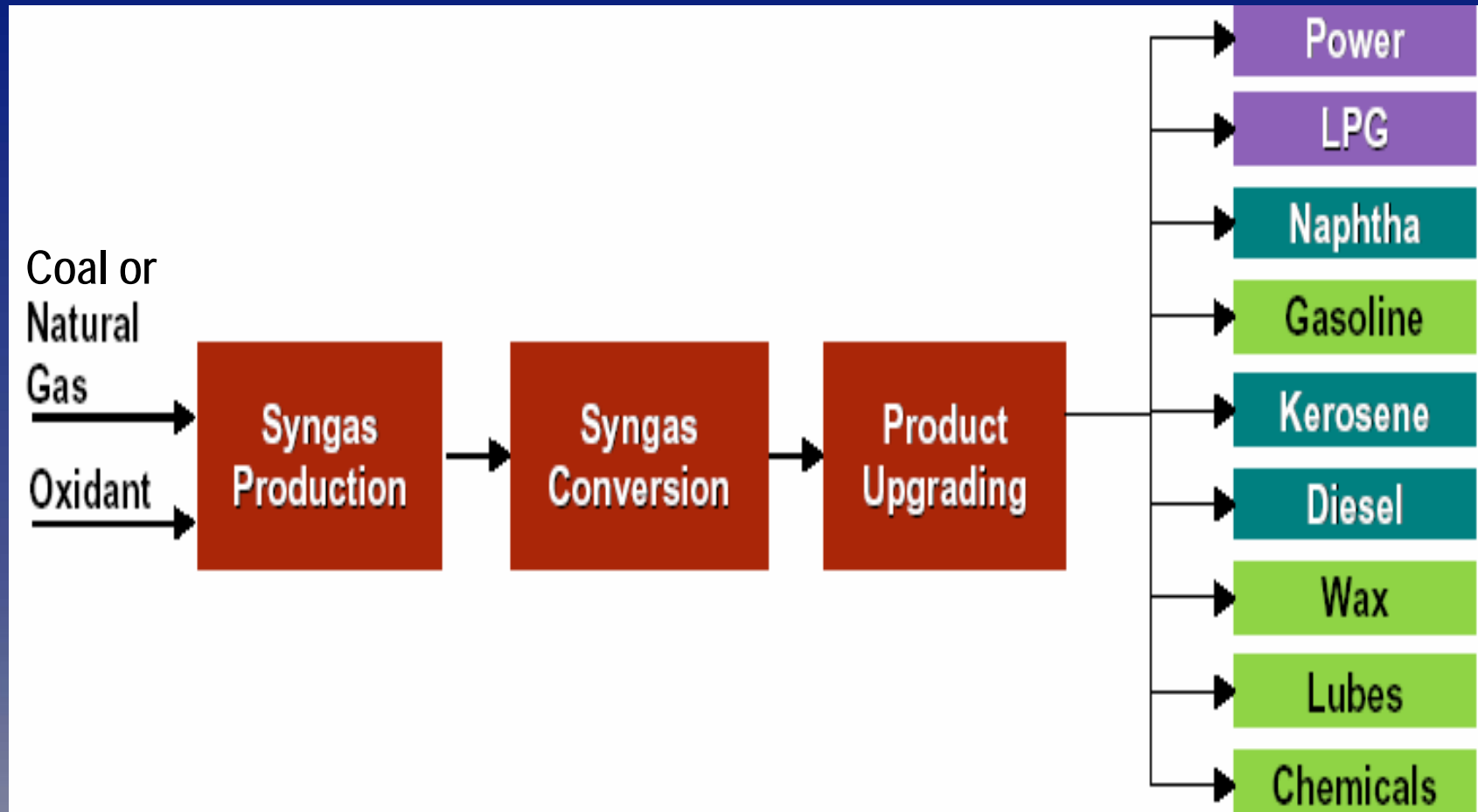
- Invented in 1920's
- Developed pre WW II Germany
- Commercialized in South Africa 1955 and again late 70's/early 80's
- Other ventures built based on natural gas (GTL), Shell, PetroSA
- Sasol experience of 50 years: >200 different products; cumulatively >1.5 billion barrels of fuel; Synfuels 28% of South African transportation fuels demand.



What Would a Large CTL Plant Look Like?



FT Products





KY CTL Case Studies



Case No.	Capacity BPD	Configuration	Coal Type
1	10,000	No Carbon Capture	E KY
3	10,000	No Carbon Capture	W KY
5	10,000	With Carbon Capture	E KY

Source: Mitretek



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Coal Input and Products

	Case 1	Case 3	Case 5
	10,000 BPD E KY w/o CC	10,000 BPD W KY w/o CC	10,000 BPD E KY w/ CC
Coal Feed (TPD)	4,844	5,438	4,844
Naptha (BPD)	3,507	3,507	3,507
Diesel (BPD)	7,495	7,495	7,495
Parasitic Power (MWe)	132	143	148
Power Sales (MWe)	52	44	37
Sulfur (TPD)	37	180	37

Source: Mitretek



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Coal Feed (TPD) w/ Size

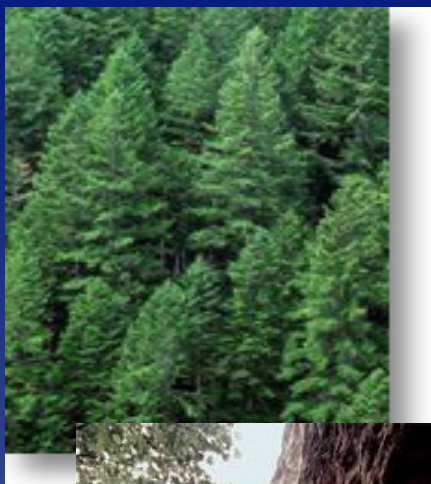


10,000 BPD Liquids	5000 Tons Coal
30,000 BPD	15,000 tons
60,000 BPD	30,000 tons
100,000 BPD	50,000 tons





Air Emissions



	Case 1	Case 3	Case 5
	10,000 BPD E KY w/o CC	10,000 BPD W KY w/o CC	10,000 BPD E KY w/ CC
Coal Feed (TPD)	4,844	5,438	4,844
CO2 Captured (TPD)	0	0	7,249
CO2 Released (TPD)	7,990	8,272	744
SOx Released (TPD)	.007	.0031	.007
NOx Released (TPD)	.4622	.463	.462

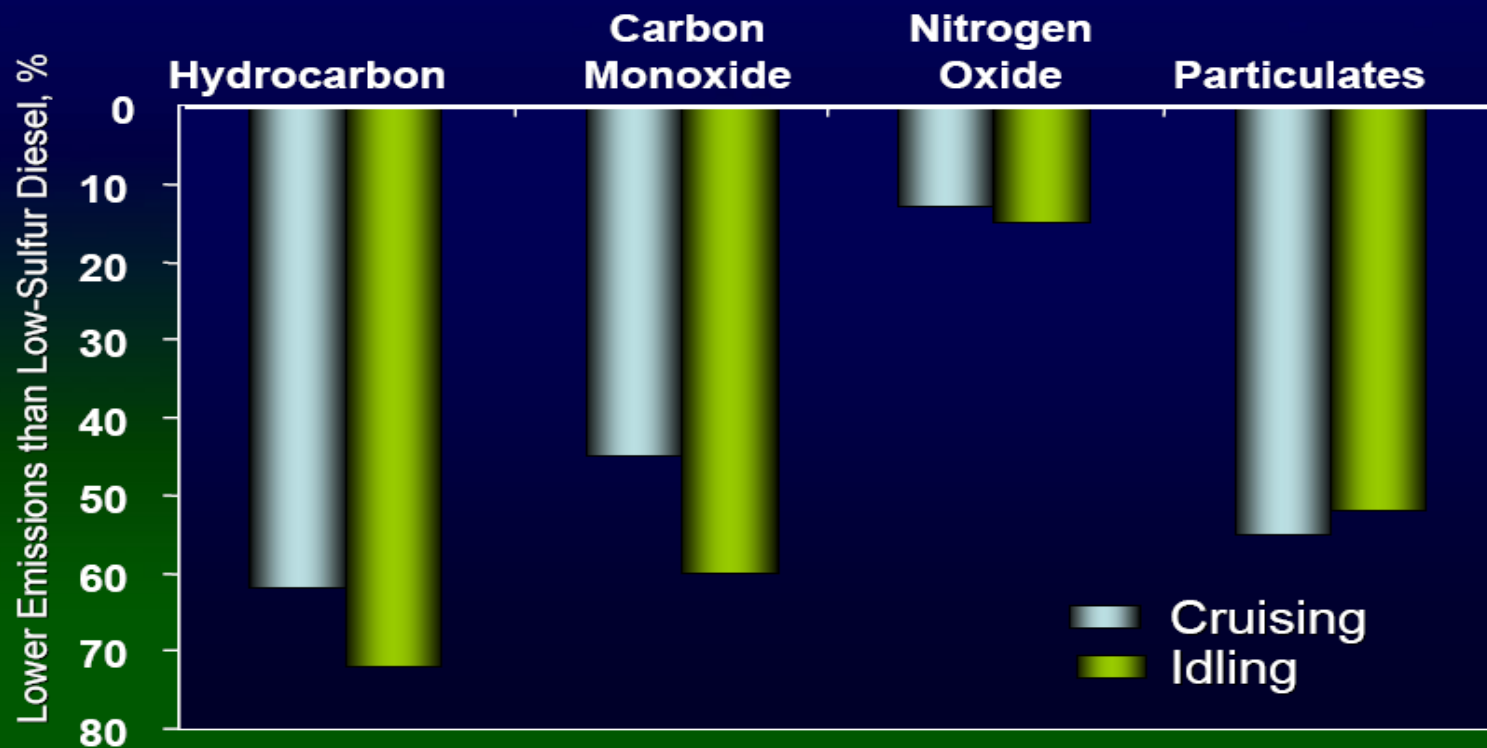


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Source: Mitretek

Fuel Quality

Reality: Regulated Emissions Lower in FT



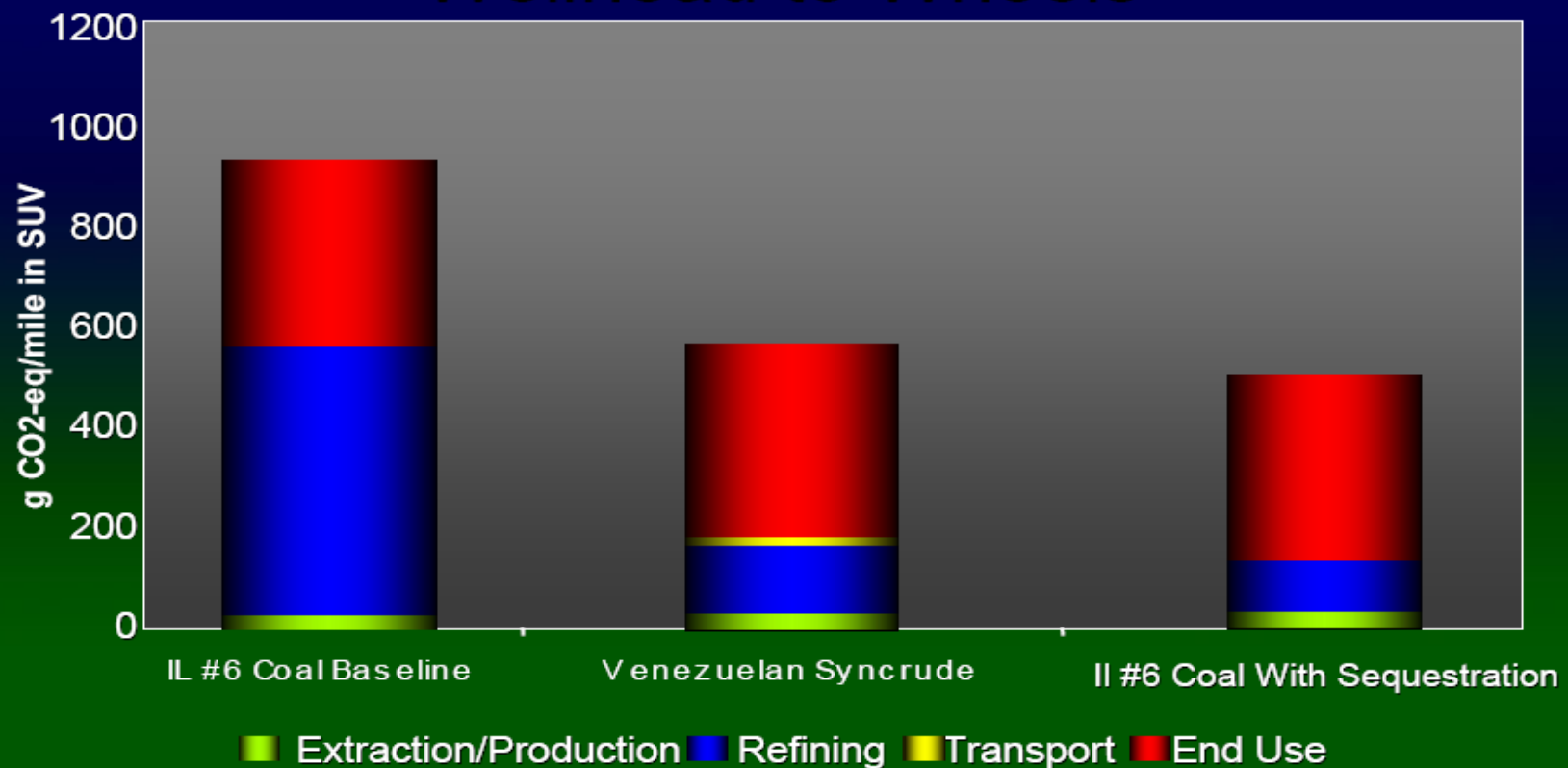
U.S. Military Testing





CTL Carbon Footprint

Reality: Less Carbon Dioxide Wellhead to Wheels



Based on Marano-Ciferno CTL Study for NETL





Source of CTL Emissions

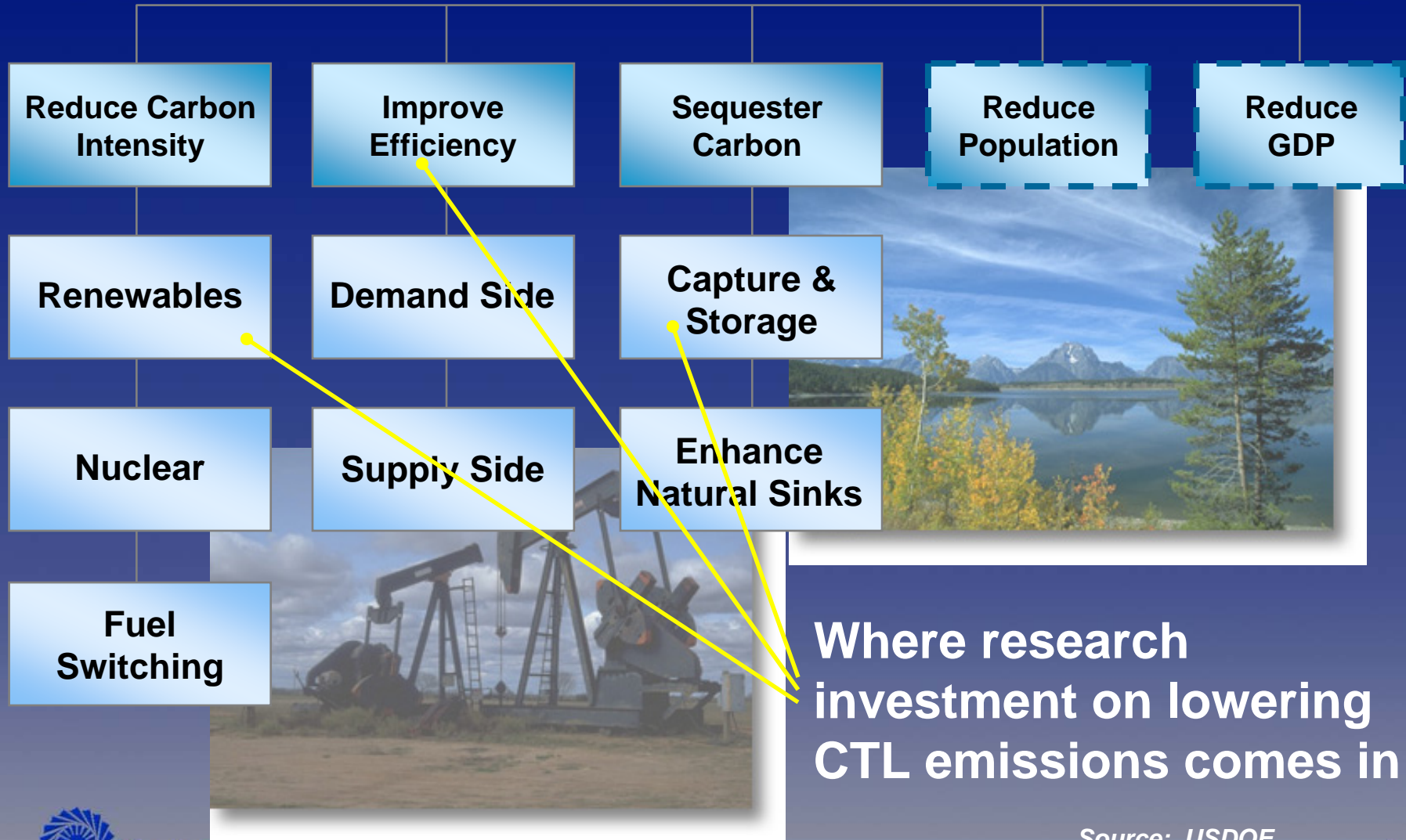
- Power production
- Small amount as byproduct of FT
- NEED FOR HYDROGEN
 - Coal has a lot of carbon, little hydrogen
 - Fuel has slightly more hydrogen than carbon
 - Use water gas shift reaction
 - Water + CO to Hydrogen + CO₂
- Alternative sources of hydrogen can reduce this impact





Technology and Innovation

Can Lead to Reductions in Carbon Emissions



Sasol Plants At Secunda ~ 1985



Initial capacity: 2 x 50,000 bbl/d, Then 40% of SA's fuel needs, now 28%; Cost \$6bn; Site 13 km² (~3,200 acres)
Two plants built sequentially with \$500m saving
Construction work force 28,700 from 39 nationalities
250 million man-hours. Now 160,000 bbl/d





CAER FT Program



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CAER Capabilities in FT

- Catalyst Preparation
 - Developed iron catalysts for low, intermediate, and high molecular weight products
 - Large scale preparation capability (150 pounds of catalyst for DOE)
- Catalyst Characterization
 - Both in-house and with other universities and National Labs
- Catalyst Testing
 - 16 1-liter continuous stirred tank reactors
 - 4 fixed bed reactors – 1 for supercritical operations
 - 2" id x 6' tall bubble column reactor
- Product Characterization
 - Developed detailed analysis capability
 - adapted by a major company currently in FT production
- Isotopic Tracers

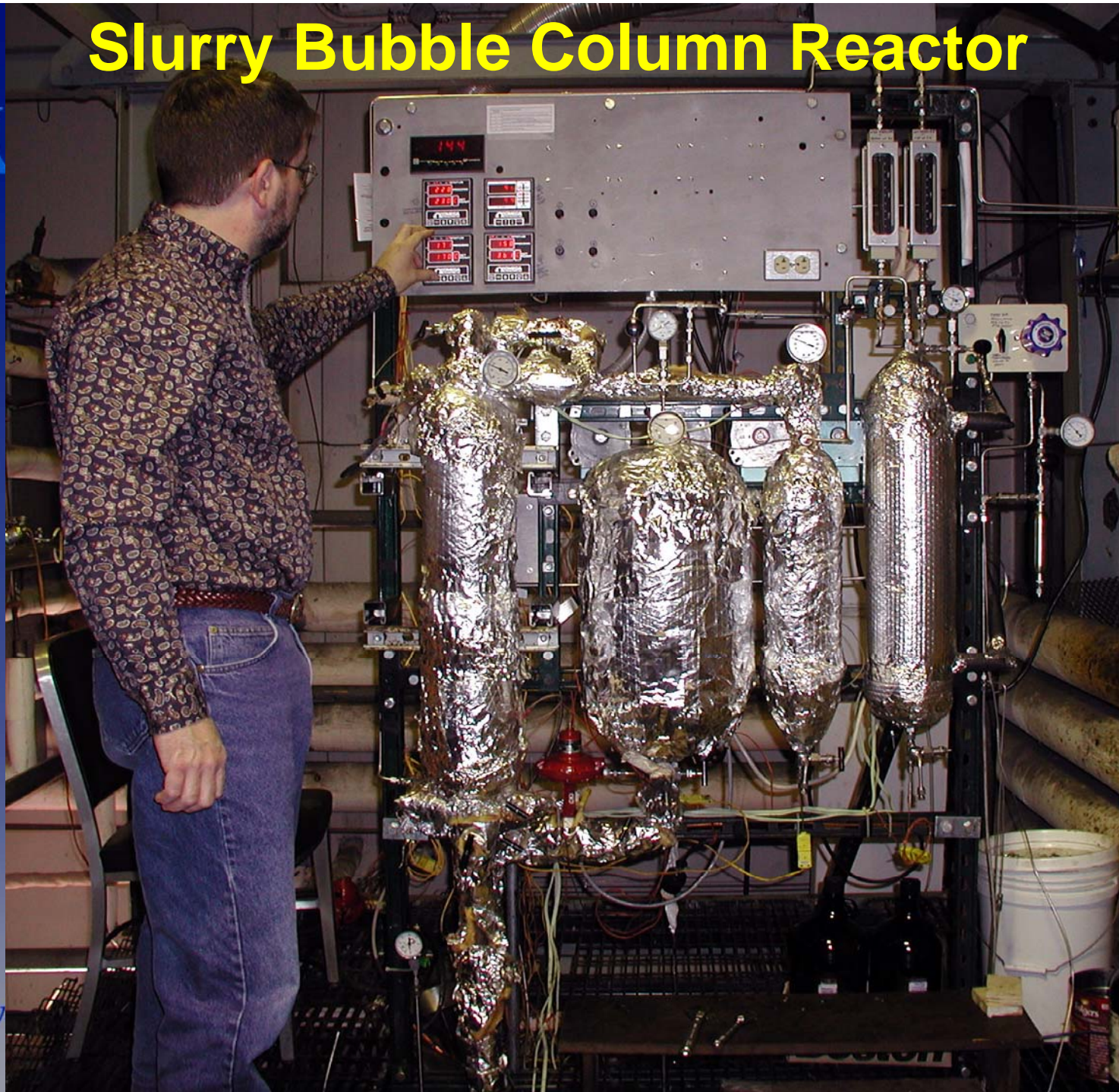


UK CSTRs

Five (of 16) 1-liter continuous stirred tank reactors (CSTR) and gas flow control panel



Slurry Bubble Column Reactor

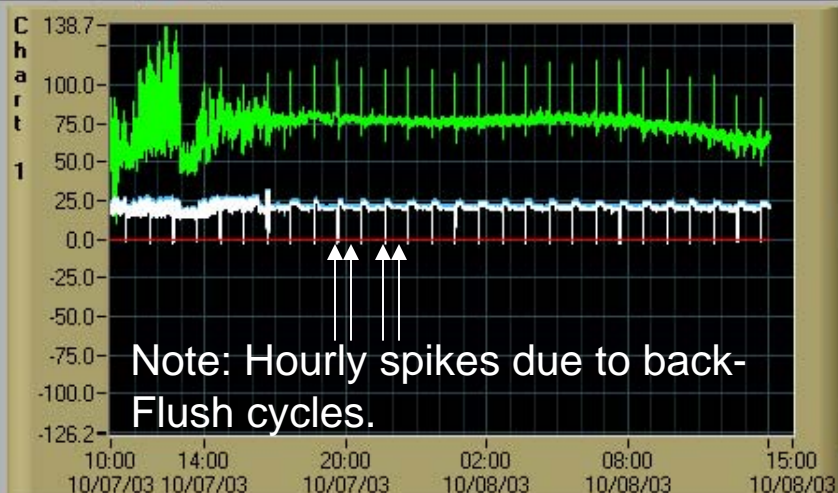


UK

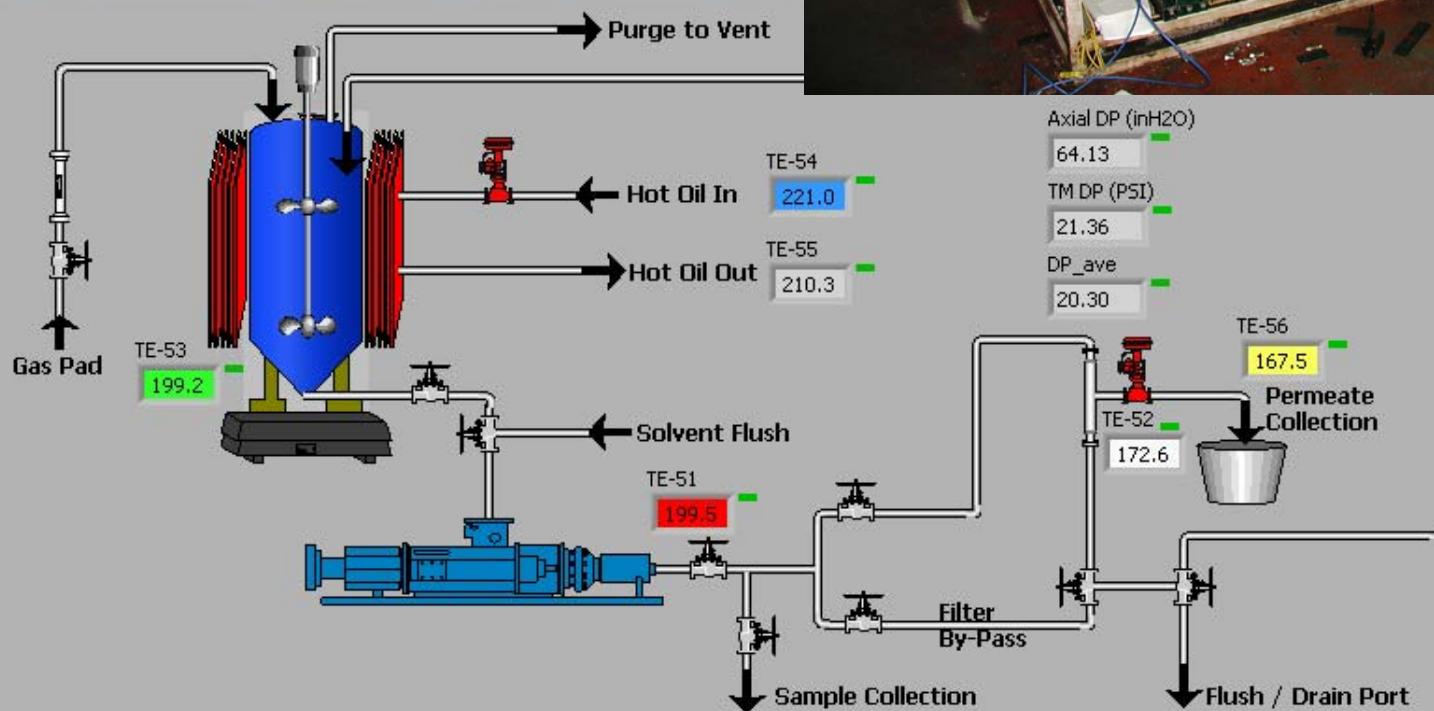


Filtration DAQ.vi

File Edit Operate Tools Browse Window Help



FT Wax Separation Unit



Axial DP (inH₂O)

64.13

TM DP (PSI)

21.36

DP_ave

20.30

Start Time

10:00

10/07/03

Stop Time

15:00

10/08/03

Save Times

OK



CAER Emissions Control Program



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CAER Research on Air Quality

- The research at CAER on air quality could be categorized into three groups – pollution control from coal utilization, NO_x reduction from automobile, and emission control from livestock production

- **Coal Utilization**

- CO₂ Capture and Carbon Management
- SCR Catalyst Management
- “Blue Plume” SO₃ mitigation
- Mercury Emission and Control



- **Automobile**

- NO_x reduction



- **Livestock Farm**

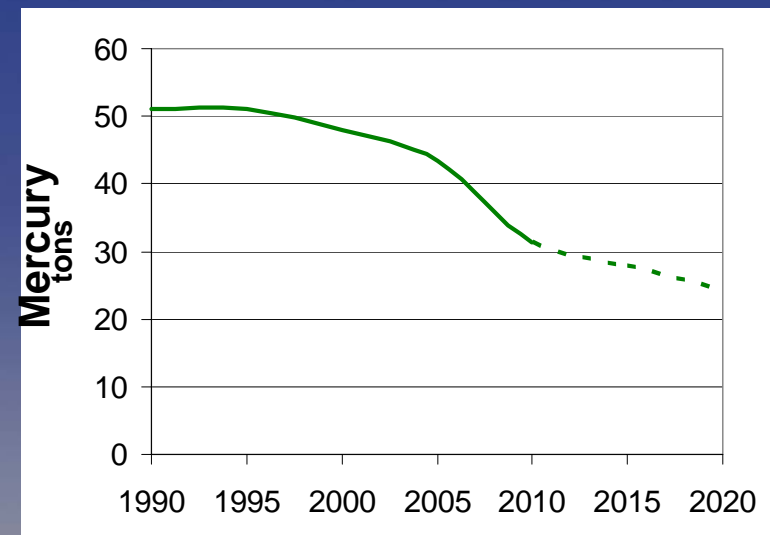
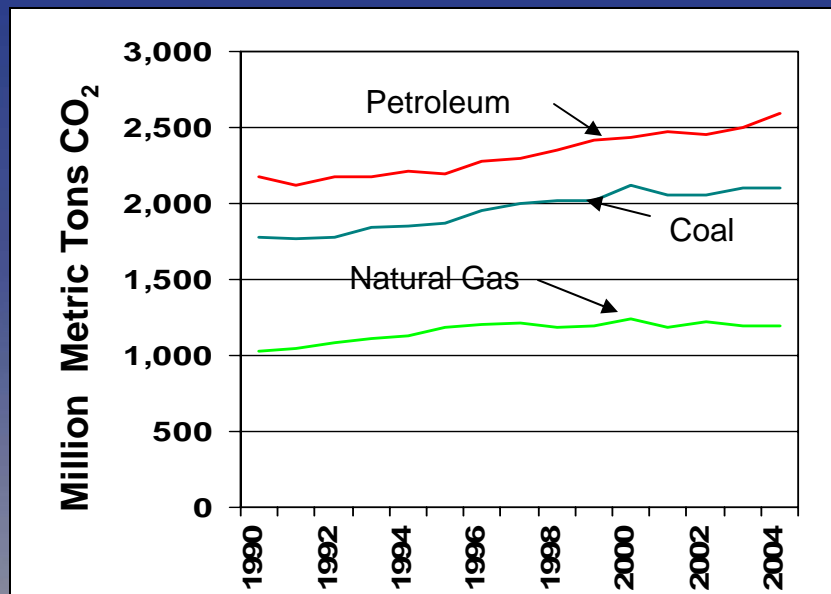
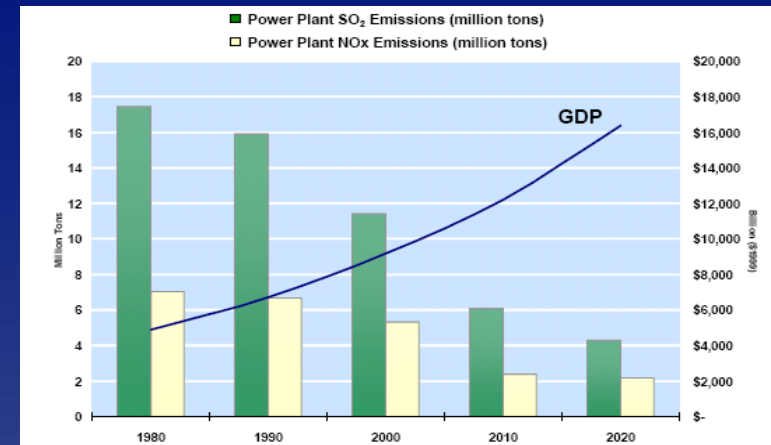
- CH₄
- NH₃
- Solid waste



The Emissions & Control Related to Coal-Fired Power Plant



- PM – ESP or FF
- Acid rain
 - SO_x – FGD
 - NO_x – Low NO_x Burner, SCR, SNCR
- Mercury – PAC, co-benefit
- CO₂ etc GHGs
- New concerns.....



Driving Forces for Environmental Research



- **Environmental Regulation**
 - Clean Air Interstate Rule (CAIR) on SO₂, NO_x and PM
 - 2005 upon Clear Act
 - Clean Air Mercury Rule (CAMR) on mercury
 - Kyoto Protocol on climate change (CO₂)
 - On-going CO₂ -reduction debate in US Congress
 - 6 bills in house and senator
- **Cost Reduction and Profitability**
 - Biomass tax credits/Green Energy Premiums
 - Cap-and-Trade system



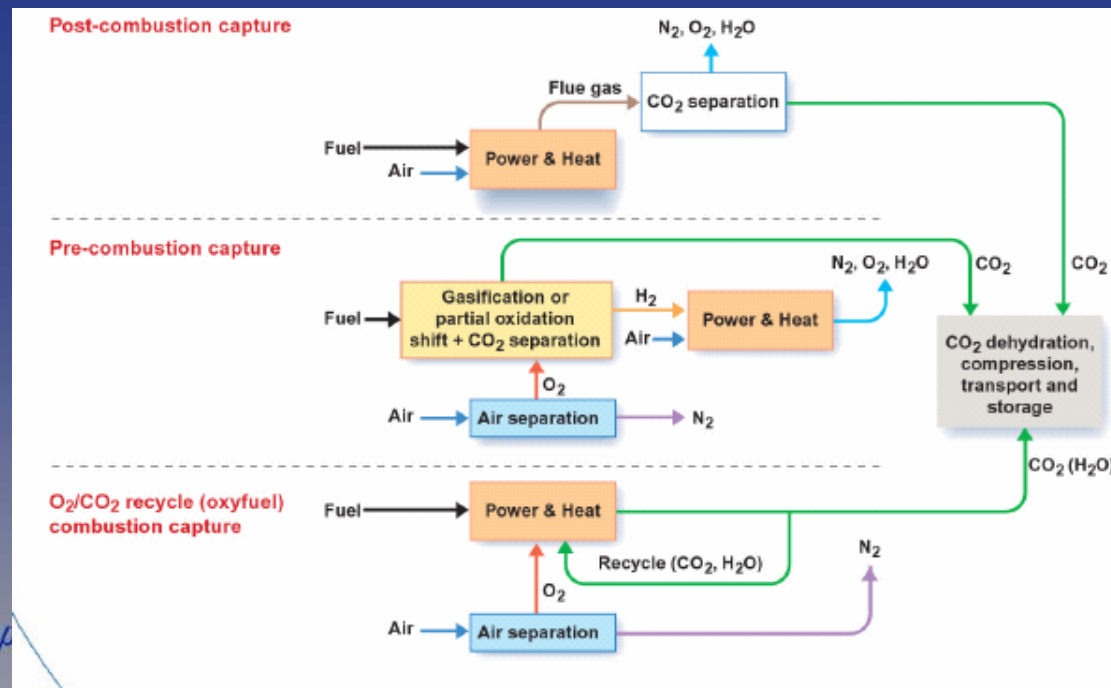
CO₂ Capture from Electricity Generation

Challenges

- Low CO₂ concentration in flue gas
 - High direct compression cost
 - High transportation cost
- CO₂ Enrichment Process
 - High energy consumption (50-80% increasing in COE)
 - appropriate technologies

CAER Target

- Reduce energy penalty reduction vs. heat integration, new solvent development, and new breakthrough concepts
- New Technology development in the areas of in-suit combustion (oxyfuel) and post-combustion CO₂ capture



CO₂ Capture Research



- **Two Supported by E-ON US:**
- ***Post-Combustion Process**
 - Solvent-based CO₂ capture technologies
 - New concept development
 - Solid additives
 - Membrane for solution separation
- ***In-situ process (No external ASU)**
 - Pressurized Chemical Looping Combustion Combined Cycle (PCLC-CC)
- **One for existing PC supported by GOEP**
 - Feasibility Study on Using Algal Capture and Utilize CO₂ Source from Kentucky Power Plants
- **One for IGCC supported by CAER**
 - Activated Carbons for CO₂ Capture from Coal-derived Pitch/Polymer Blends
- **R&D Focus:**
- **Solid Sorbent**
 - Low temp Na₂CO₃/NaHCO₃ cycle
 - New sorbents
- **Solvent Based**
 - MEA, KS, and Ammonia group
 - New solution and separation



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Stripper

Scrubber



Other Approach for CO₂ Management



- Energy Conservation and Efficiency Improvement
- Carbon-less or –free resources such as biomass, nuclear, wind, solar, etc



Source: Scott Willis of the San Jose Mercury News (California)

Standard of Living & Fossil Fuels Consumption

The fundamental greenhouse gas (GHG) issue of fairness

The USA must set the GHG example for others, especially China

SFA Pacific, Inc.

- CAER is conducting several projects on biomass densification
 - Biomass briquetting and agglomeration
 - Biomass gasification/pyrolysis
 - Biomass liquefaction
 - Green power production using bio-diesel by-product Glycerin

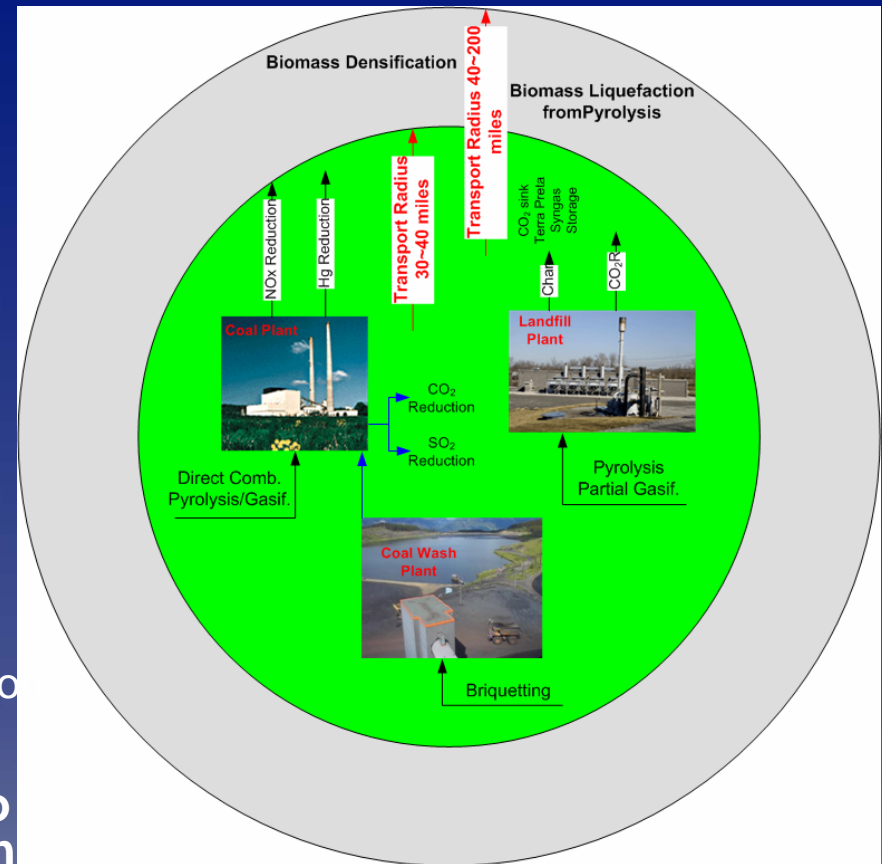


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Biomass Process Scheme Radius of Feasibility



- Current CAER Research Activities
 - **Briquetting and Agglomeration**
 - Resolution of technical obstacles impeding commercial production of briquetted fuels from coal and biomass wastes;
 - Production of biomass briquettes as an alternative fuel
 - **Biomass gasification/pyrolysis**
 - Biomass fast pyrolysis with in-situ catalyst to yield high-Btu oils
 - **Biomass liquefaction**
 - On-Site Thermochemical Densification of Biomass
 - **Integrated biomass gasification to PC for green electricity generation**
 - Biochar as soil amendment and Hg sorbent



Apparatus at CAER



Fast Pyrolysis Cold Model



Thermochemical Extruder



Briquetter



Blue Plume from the Wet FGD



-Status, Solution and CAER Approach-

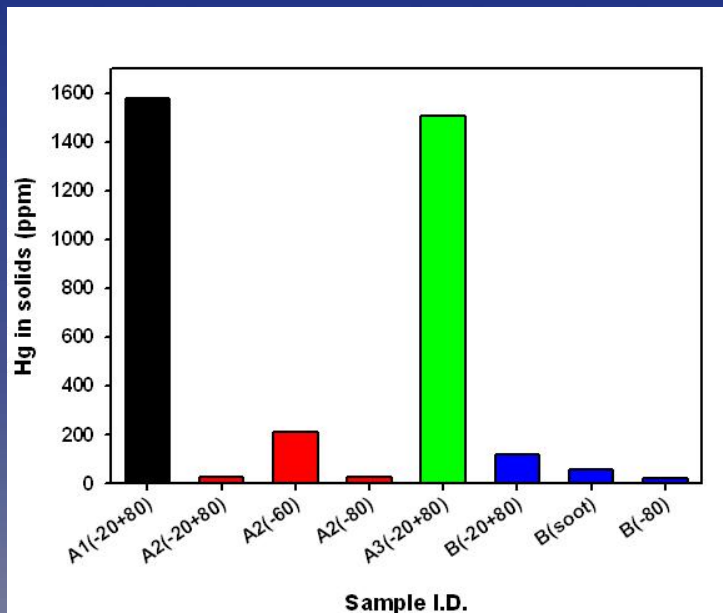
- **Major due to SO_3**
 - Produce from combustion S
 - In the range of 0.5-1.5% of SO_2
 - Visible if >2.5 ppm
 - Get worse with SCR (1% extra)
 - Mist (airborne) @ quench at WFGD entrance interface
- **CAER's stage-cooling concept**
 - A cold surface to allows SO_3 to condense to liquid droplets and be trapped by this surface.
 - The untrapped droplets binder to a solid particle to form over micro-scale particles, and finally be captured by WFGD.
 - The features:
 - no sorbent/chemical injection is involved
 - no impact on the performance of downstream components or processes.



CAER Activities on Mercury Mitigation

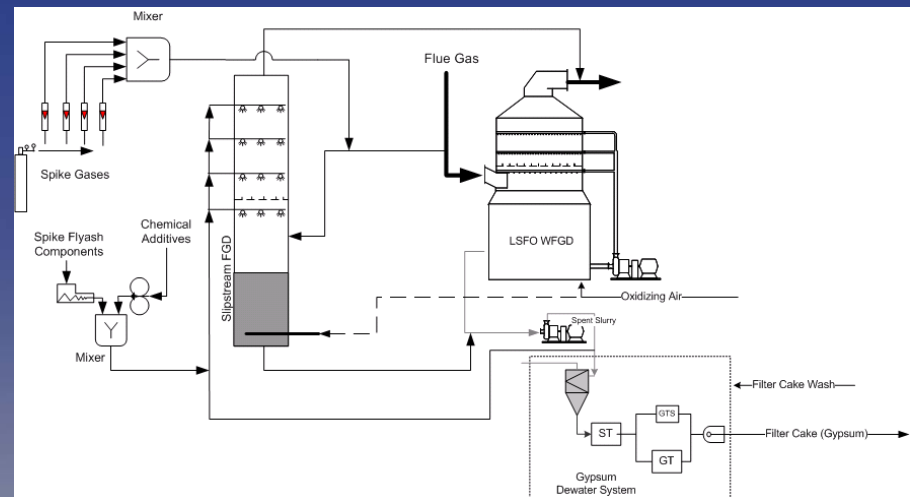
- Sorbent Development and Evaluation:

- Investigation to assess the potential use of gasifier slag carbons for mercury and NO_x capture from combustion flue gases



- Hg Measurement and Mitigation:

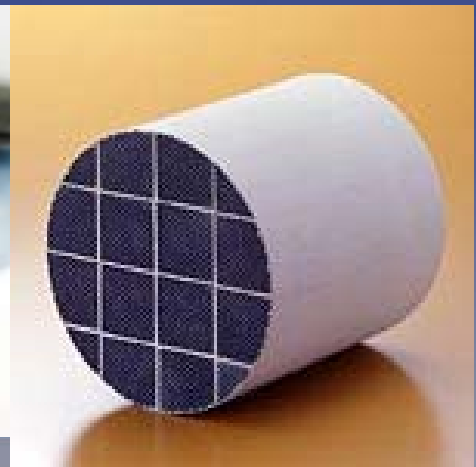
- Over 20 power plants
- Impact of SCR and FGD on Hg capture
- Hg re-emission across WFGD
 - Identify the root causes
 - Find appropriate approaches for achieving mercury removal efficiency >85%



Emission Control from Automobile



- Development of Lean NO_x trap (LNT) catalysts:
 - investigation of aging mechanisms in LNT catalysts for NO_x emission abatement from lean (i.e., oxygen-rich) exhaust gas
 - sponsored by DOE
- Hydrocarbon SCR:
 - NO_x reduction in lean exhaust gas using hydrocarbon reductants
 - sponsored by the Coordinating Research Council



Environmental Catalysis Research at CAER



Completed projects:

Development of catalysts for NO oxidation:

- aim was to identify a catalyst that is active for oxidation of NO to NO₂ under typical flue-gas conditions, in order to improve SCR kinetics (i.e., $\text{NO} + \text{NO}_2 + 2\text{NH}_3$)
- sponsored by DOE (University Coal Research Program)

Hydrocarbon SCR:

- development of novel base metal catalysts for NO_x reduction using hydrocarbon reductants in lean exhaust gas;
- sponsored by KSEF



Future Research Directions



Coal Fuel Alliance



Obama-Luger
Amendment - Section
417, 2005 EPAct

- Improve research capabilities
 - 6" slurry bubble column FT reactor
 - refinery unit for wax upgrading to fuels
- Focus on producing test fuels
- Labor force development
 - training engineers / operators



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Coal and Biomass

- Enhanced modular reactor systems
- Improved catalysts for water-gas-shift
 - Reduce unwanted CO₂ formation
- Use of biomass in FT processes
 - Biomass gasification
 - Gas cleaning
 - Utilization of biomass as hydrogen source
- Co-feed of Coal and Biomass for CTL





Biofuels Laboratory

- Expand facilities for biodiesel production
 - Funded by GOEP and KREC
- Fuel quality testing
- Biomass gasification for producer gas production (electric power)





Kentucky Advanced Power Generation Consortium

- Envisioned as a State-UK-Industry consortium
- Build on E-ON US investment in carbon management and emissions control
- Develop more energy and cost effective carbon management technologies
- Need specific materials, controls and waste management solutions
- Allow early adoption of technologies by industry



UK

Questions?



FutureGen

(Artist rendering)



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Source: USDOE